

PATENT APPLICATION
OF
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FOR
COLOR CONVERSION METHOD AND APPARATUS

TO WHOM IT MAY CONCERN:

Be it known that David A. Frazer, a *citizen of the United States of America*, and Yuh-Ming Chen have invented a new and useful Color Conversion Method and Apparatus, of which the following is a specification:

BACKGROUND OF THE INVENTION

Field of the Invention

The invention relates in general to image processing. More particularly, this invention relates to a method and apparatus
5 that accelerates color space conversion by employing a multi-dimensional and multi-port memory.

Description of the Related Art

Color Copiers or other imaging devices capture an image
10 from an input device and attempt to create a suitable duplicate on an output device.

The input device has inherent properties and characteristics with regard to the sensing process in a document. An example of an input device is a Charged Coupled
15 Device ("CCD") scanner. A CCD sensor is typically composed of three sensors for each pixel to be sensed. Each of the three sensors responds to a different wavelength of light. Typically, the wavelengths are close to Red, Green and Blue (RGB).

The output device has inherent characteristics with regard
20 to the process of creating an image. One such example is a color laser printer. The output device typically creates an image using four different colors, i.e. Cyan, Magenta, Yellow

and Black (CMYK).

Color Management is defined as the task of accurately converting color information of one form or space to that of another space. This might be compared to the way that points in
5 space or in a graph can be converted from a Euclidean space to a Spherical or other coordinate system.

The classical "textbook" method for converting color from one representation to another is by matrix multiplication. A three-component (e.g. RGB) element is multiplied by 3x3 matrix
10 to generate a value in the new space. Industry standards exist for these matrices, such as those used in color television or JPEG compression.

The matrix-multiplication method demands that the conversion process be rather ordinary, in that the three-
15 dimensional surface generated is continuous and without irregularities. For best results, one might desire that a different 3x3 matrix value set be used to convert various regions of the input color space. This is rather cumbersome, and the typical implementation is by table lookup.

20 The lookup process uses a table, usually implemented in memory such as SRAM or DRAM, that provides an output value for every input value. However, such a method requires a large

amount of memory. For example, table-based color space conversion from RGB to CMYK would ideally translate every incoming 24-bit RGB value to a unique CMYK value. This would require a table with 16 million entries of 32 bits, or 64 MB of
5 memory.

Due to practical limits on the size of the memory that can be used to store the color lookup table, only discrete data points, or nodes, are stored in the color lookup table. As a result, it is often necessary to interpolate between a set nodes
10 adjacent to a given image color to determine the desired output color for a destination device.

Typically, the adjacent nodes are separately accessed from the lookup table, thus requiring multiple accesses to memory. For example, in the three-dimensional RGB input space, a set of
15 eight nodes forming a cube around a color pixel must be accessed. This proves to be inefficient, given the plurality of pixels in input images.

Therefore, the need arises for an image processing device that allows for a single access of memory for interpolation of
20 data points, thereby expediting input image conversion.

In U.S. Patent No. 6,246,396, Gibson discloses an apparatus for converting an input image in an input color space to an

output image in an output color space. Gibson does not
interleave memory by placing odd and even indices into separate
lookup tables. The subject invention separates odd and even
indices for all three dimensions, resulting in eight separate
5 lookup tables.

SUMMARY OF THE INVENTION

Accordingly, one object of the present invention is to
provide an image processing device that expedites color space
10 conversion.

A second object of the invention is to provide an image
processing device that allows for a single access of memory for
interpolation of data points.

A third object of the invention is to provide an image
15 processing device color space conversion in multiple dimensions.

A fourth object of the invention is to provide an image
processing device color space conversion using multiple ports.

To achieve these and other advantages and in accordance
with the purpose of the invention, as embodied and broadly
20 described herein, the invention provides an apparatus and method
for converting an input image with a plurality of pixels to an
output image using an N-dimensional conversion table with a

plurality of nodes. The apparatus has a set of RAMS for storing odd-indexed nodes and even-indexed nodes for each dimension of the N-dimensional table. The apparatus also has means for retrieving for each pixel a set of output color values corresponding to nodes adjacent to the pixel in the conversion table. Finally, the apparatus has means for interpolating within each set of output color values to produce the output image.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a graphical depiction of a prior art lookup table in three-dimensions.

FIG. 2 is a graphical depiction of a three-dimensional lookup table separating odd and even indices along the X-axis.

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FIG. 3 is a graphical depiction of a three-dimensional lookup table in accordance with the present invention.

FIG. 4 is a diagram illustrating address increment hardware for the present invention.

FIG. 5 is a graphical depiction of the distribution of RAMS within a three-dimensional lookup table for the present invention.

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FIG. 6 is a diagram illustrating the hardware configuration for the lookup table of FIG. 5.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

5 Referring now to FIG. 1, a graphical depiction of a prior art lookup table in three-dimensions is shown. The three-dimensional lookup table can be envisioned as a cube 10 containing nodes 11 at predetermined addresses along the X, Y and Z axes.

10 Still referring to FIG. 1, an input color 12 contains address components X_1 , Y_1 and Z_1 . Typically, input color 12 will not coincide exactly with the predetermined address of a node. Therefore, address components X_1 , Y_1 and Z_1 are used to determine 8 vertices V_1 thru V_8 adjacent to input color 12. Vertices V_1
15 thru V_8 all fall within a cube. Given the index coordinate of (x,y,z) , for example, the following locations will be read:
 (x,y,z) , $(x,y+1,z)$, $(x,y,z+1)$, $(x,y+1,z+1)$, $(x+1,y,z)$,
 $(x+1,y+1,z)$, $(x+1,y,z+1)$ and $(x+1,y+1,z+1)$. An output value corresponding to input color 12 is approximated by interpolation
20 of vertices V_1 thru V_8 .

Still referring to FIG. 1, obtaining an output value for input color 12 requires separately accessing vertices V_1 thru V_8 .

This is because the lookup table is implemented on a single SRAM. Because a single memory bank is used, 8 separate accesses to memory are necessary to process every pixel in a given input image. This proves to be an inefficient process for color space
5 conversion.

With reference to FIG. 2, a graphical depiction of a three-dimensional lookup table separating odd and even indices along the X-axis is shown. In this embodiment, each half of the lookup table 20 is implemented on a separate SRAM. By dividing
10 the lookup table 20 into two pieces 21 and 22, vertices V_1 thru V_4 can be accessed at the same time as vertices V_5 thru V_8 . All 8 vertices need not be separately accessed from memory. Instead, 2 groups, each containing 4 nodes, can be simultaneously accessed from their respective SRAM. This procedure cuts the
15 time to access the 8 nodes surrounding input color 12 in half.

Referring now to FIG. 3, a graphical depiction of a three-dimensional lookup table in accordance with the present invention is shown. The lookup table separates odd and even indices along the X-axis, Y-axis and Z-axis. In this
20 embodiment, each of the eight portions of the lookup table is implemented on a separate SRAM. By dividing the lookup table into cubes 31 thru 38, vertices V_1 thru V_8 corresponding to input

color 12 can be accessed at the same time. Instead of performing separate accesses to memory for each these vertices, all output values of the vertices are simultaneously obtained.

With reference to FIG. 4, a diagram illustrating address increment hardware for the present invention is shown. For purposes of this example, a 1-dimensional table with 17 elements will be used. The index into the table is a five-bit number with valid values from binary 00000b to 10000b, or from 0 to 16 inclusive. Given an algorithm that requires simultaneous access to two table elements at indices (or addresses) of n and $n+1$, the table is split into two separate tables with one containing the contents of all the even addresses and another containing all of the odd addresses. When the index into the table is even (e.g. 0,2,4..) then the index of 000b (the three most significant bits of the index value) into each table will in fact retrieve the values from addresses 00000b and 00001b from the original table.

Still referring to FIG. 4, when the index is an odd value, then the even table address needs to be incremented. For example, if the 4 most significant bits of the input color are 0101b, then locations 0101b and 0110b will be accessed from the original un-split table. In the split table arrangement, only

the 3 most significant bits of the input color are used, so the input address would be 010b. At address 0010, values of 4 and 5 will be retrieved, but the subsequent value from the even table is needed. Hence when the four most significant bits of the input color are odd, the address to the even table must be incremented in order to retrieve the desired values from entries n and n+1 of the original, un-split table. This concept must be extended to all three dimensions.

Referring now to FIG. 5, a graphical depiction illustrating the distribution of RAMS within a three-dimensional lookup table for the present invention is shown. This embodiment shows a 17x17x17 lookup table formed as a cube 50. The lookup table is composed of a 16x16x16 core 51 implemented in 8 RAMS.

Still referring to FIG. 5, faces 52 thru 54, edges 55 thru 57 and corner 58 form a skin around core 51. Faces 52 thru 54 are 1x16x16 each, edges 55 thru 57 are 1x1x16 each, and corner 58 is 1x1x1. Faces 52 thru 54, edges 55 thru 57 and corner 58 are implemented on RAMS separate from the core. Like the core, the additional RAMS are implemented by separating odd and even indices in the appropriate number of dimensions. This allows for simultaneous access of vertices V_1 thru V_8 for input color 12.

With reference to FIG. 6, a diagram illustrating the hardware for lookup table of FIG. 5 is shown. For purposes of this embodiment, 24-bit incoming color data will be used. Only the four most significant bits of each color component are used to index into the table, and the lower four bits will be used for a three-dimensional interpolation within the 8 value cube that is supplied by the table.

Still referring to FIG. 6, index values 0 thru 14 within the 4-bit range of 0 thru 15 will only access the inner 8 RAMS, i.e. RAMS 0 thru 7. The inner 8 RAMS represent core 50 in FIG. 5. When any of the color components equals 15, some components will be retrieved from the outer 8 RAMS, i.e. RAMS 8 thru 15. The outer 8 RAMS represent faces 52 thru 54, edges 55 thru 57 and corner 58 in FIG. 5.

Still referring to FIG. 6, hardware 60 includes address generation logic 61 for accessing RAMS 0 thru 15. Address generation logic 61 determines which points of the eight vertices of the cube will come from which RAMS.

Other embodiments of the invention will appear to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples to be considered as exemplary

only, with a true scope and spirit of the invention being indicated by the following claims.